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Sludge conditioning by sonication and sonication-chemical methods

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Abstract

This paper investigated the potential impacts of sonication on sludge dewaterability and the optimal conditions. Both sonication conditioning and sonication-chemical co-conditioning were tested. Final water content of dry sludge was used to represent the sludge dewaterability. The results showed that sonication significantly changed the sludge dewaterability and the changes were strongly influenced by the ultrasonic power density and time. The best sonication for sludge conditioning, alone or together with chemicals, was 7 s and 0.8 W/ml. The optimal energy dose was 960 kJ/kgDS while energy input higher than 1200 kJ/kgDS deteriorated the sludge dewatering. Sonication alone only reduced the sludge specific resistance to filtration (SRF) by 40% and the final water content to 90%; thus, chemical conditioning was necessary. Combination of FeCl₃ and polyacrylamide (PAM) was very effective for sludge conditioning and the optimal PAM/FeCl₃ was 0.01. When chemicals were used, sonication effectively reduced the necessary chemical dose by 40-50% but showed little improvement in SRF. The best sludge conditioning parameters were found to be: sonication for 7 s at 0.8 W/ml, 1.5 g/L FeCl₃, and 15 mg/L PAM. With such conditioning, sludge SRF decreased by 91% and the final water content was 72.8%

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Keywords: Sludge; dewaterability; ultrasonic conditioning; FeCl₃; PAM

1. Introduction

Activated sludge processes are the most widely used methods for treating municipal and industrial wastewater, but these processes generate large amounts of excess sludge. In typical activated sludge processes, the sludge yield coefficient is 0.5 [1]. Sludge has a water content of 99.2-99.8%, therefore, dewatering is the paramount important step in sludge treatment in order to reduce the volume and

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handling cost. However, excess sludge is “super-compactable” and its dewatering is difficult and remains the most expensive wastewater treatment process [2]. Typical sludge dewatering involves chemical conditioning and mechanical dewatering. Chemicals used include alum, iron chloride, iron sulfate, polyelectrolytes such as polyacrylamide (PAM). Addition of polyelectrolyte might be the prevailing sludge conditioning method that can significantly reduce the sludge capillary suction time and specific resistance to filtration (SRF), and, hence, improve the dewaterability of conditioned sludge. However, polyelectrolyte addition also means high cost and potential hazards to the environment. For example, acrylamide, the monomer of PAM, is a carcinogen. Various alternatives have been proposed for sludge conditioning including Fenton’s reaction, pH adjustment, sonication, and freezing-thawing [3-6]. Among these methods, sonication is very attractive since it is simple, easy to operate, and secondary pollution free. Sonication is known to facilitate the migration of moisture through natural channels or other channels created by wave propagation [7]. Powerful sonication can significantly change the structures and properties of sludge [8], disintegrate sludge flocs [9], enhance solid/liquid separation in cake filtration processes via accelerating the agglomeration process [10], improve bio-degradability or bioactivity of the treated sludge [9, 11, 12]. Many reports showed that proper sonication could reduce the sludge capillary suction time and bound water content by more than 50% [7, 13, 14]. By changing the sludge particle size and supernatant organic contents, sonication decreased the sludge SRF [2, 7]. However, adverse effects of sonication on sludge dewaterability were also reported [15, 16]. Intensive sonication increased the capillary suction time and polymer consumption [2, 14, 16]. Such controversial conclusions from these previous works make further study necessary to assess the role of sonication in sludge conditioning and to optimize the operation. The final water content of the dewatered sludge was used as the index to evaluate dewaterability improvement since it determines the sludge volume. Therefore, this paper is devoted to study the effects of sonication conditioning and sonication-chemical co-conditioning, and to find the best operations for both scenarios. Final water content of the dewatered sludge was used to evaluate sludge dewaterability.

2. Materials and methods

Sludge was collected from a local wastewater treatment plant that used conventional activated sludge process and Table 1 reports its characteristics. The collected sludge was stored at 4 °C before use.

Table 1. Properties of the untreated sludge	Dry weight (mg/L)	pH	SRF (m ² /g)	Supernatant COD (mg/L)	Turbidity (NTU)
Water content (%)					
99.5	5850	6.43	33.2	205	142

Two most widely used chemicals, FeCl_3 and PAM (DS112, cationic, molecule weight of around 1.2×10^7 , Baoding Yisheng), were adopted for chemical conditioning. The PAM stock solution (0.5%) was prepared by completely dissolving powder PAM in water 24 h prior to use. Before each experimental run, certain amount of stock solution was added to the sludge and mixed at 120 rpm for 1 min.

Sonication was performed using a cell device that emitted 25 kHz ultrasound waves (Kunshan Ultrasonics, China). For each experimental run, 1 L of sludge was treated in the ultrasonic device. The sonication time varied from 7 s to 120 s and the power density was from 0.1 W/ml to 1.0 W/ml. The ranges were chosen following literature reports. We observed little temperature increase or pH decrease due to the short sonication time and did not control the sludge temperature or pH. Each treatment was repeated in triplicate and average values were reported.

Sludge dewatering was achieved by centrifuging the sludge at 4000 rpm for 15 min. Sludge SRF was measured following the method of Feng et al. [2]. The pH was measured using a Hach pH meter. All other parameters were obtained according to the standard methods [18].

3. Results and discussion

3.1 Sonication conditioning

The effects of sonication on sludge dewaterability depended strongly on the sonication conditions [7, 15-17] and the most important ones are power density and sonication time. Therefore, we examined the impacts of sonication time and power on sludge conditioning, and the results were summarized in Fig. 1 and Fig. 2.

Fig. 1 showed the sonication for 7 s or 15 s improved the sludge dewaterability and reduced the final water content while sonication longer than 30 s deteriorated the sludge dewaterability. Note that the supernatant COD (SCOD) kept rising during sonication, indicating that SCOD was not directly related to sludge dewaterability. In sludge treatment, sonication for a few minutes was normally used, and long treatment up to hours was also tested for sludge disintegration and bio-activity improvement. Yin et al. [7] found that 2-4 min sonication significantly reduced sludge SRF while Wang [16] demonstrated that 5 min sonication increased the SRF greatly. From Fig. 1, we found that ultrasonic energy dose higher than 1200 kJ/kgDS was improper for sludge conditioning, which was lower than the limit of 4400 kJ/kgDS or 2000 kJ/L reported by other researchers [2, 7]. Since the ultrasonic energy dose depends strongly on the sludge characteristics and sonication operations, we could not directly compare these findings without knowing experimental details of these authors.

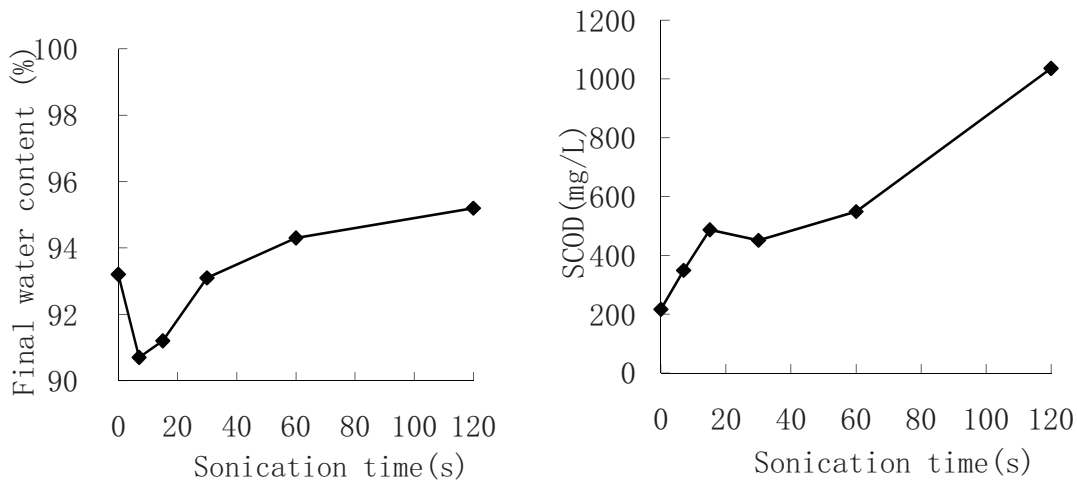


Fig. 1 Impact of sonication time on sludge dewaterability and supernatant COD, 1.0 W/ml

Fig. 2 reported the impact of ultrasonic power density on the sludge dewaterability. From 0-0.8 W/ml, stronger sonication benefitted sludge dewatering and gave drier sludge cake. However, when the sonication power was higher than 1.2 W/ml, even short sonication deteriorated the sludge dewatering. Too strong sonication significantly reduced the sludge size [8] and smaller flocs might adsorb more water and, hence, deteriorated the sludge dewaterability. The best power density for sludge conditioning was found to be 0.8 W/ml. Together with 7 s' sonication time, the optimal energy dose for sludge conditioning was 960 kJ/kgDS, which was very close to the optimal value reported before [2].

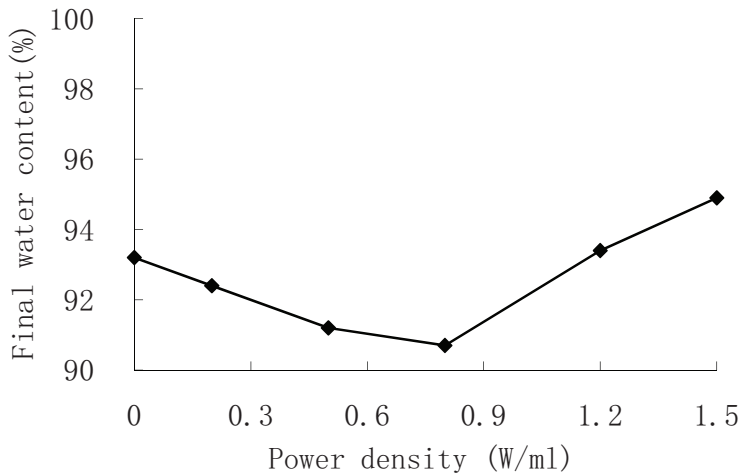


Fig. 2 Impact of sonication power density on sludge dewatering, 7 s

However, the final water content of dry sludge after ultrasonic conditioning was still high (>90%). Normally, sludge water content after mechanical dewatering was around 80% in wastewater treatment plants; such high water content was unacceptable. Therefore, sonication alone was insufficient for sludge conditioning. So chemical conditioning was tested.

3.2 Co-conditioning using sonication and FeCl_3

We first conditioned the sludge using FeCl_3 and Fig. 3 reports the results. Clearly, FeCl_3 was very effective in reducing the SRF and achieved final water content below 80% for dewatered sludge. However, we noticed that in order to obtain such dry sludge, the needed FeCl_3 dose was higher than 4.4 g/L, counting for more than 30% of sludge mass after dewatering. Such a high dose not only costs dearly but also significantly increased the amount of sludge.

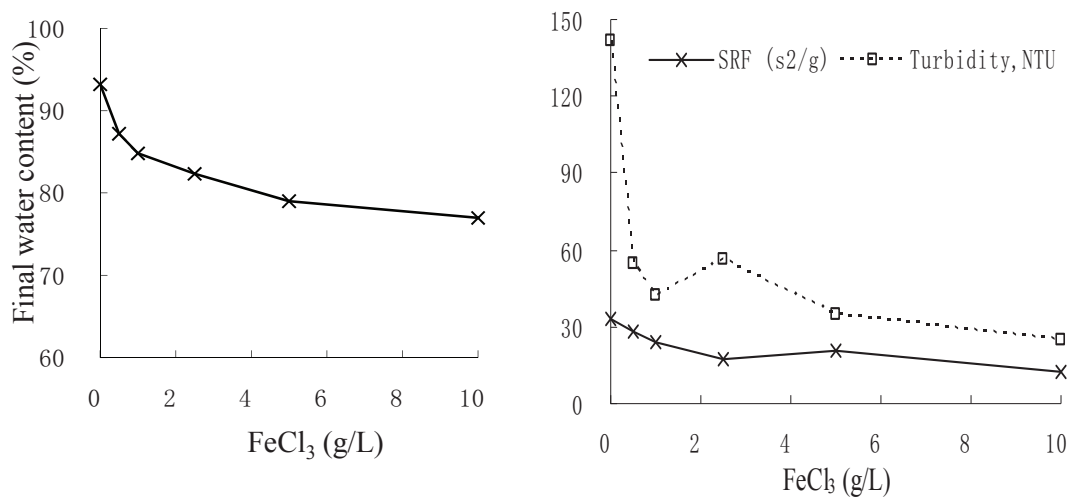


Fig. 3 Sludge conditioning using FeCl_3

We then tested the effectiveness of co-conditioning with sonication and FeCl_3 . Four different sonication conditions were used and the results were summarized in Fig. 4. Results showed that such a hybrid conditioning was very useful. Sonication cut the FeCl_3 dose by almost 50% and now 2.2 g/L chemical was sufficient to achieve 80% final water content.

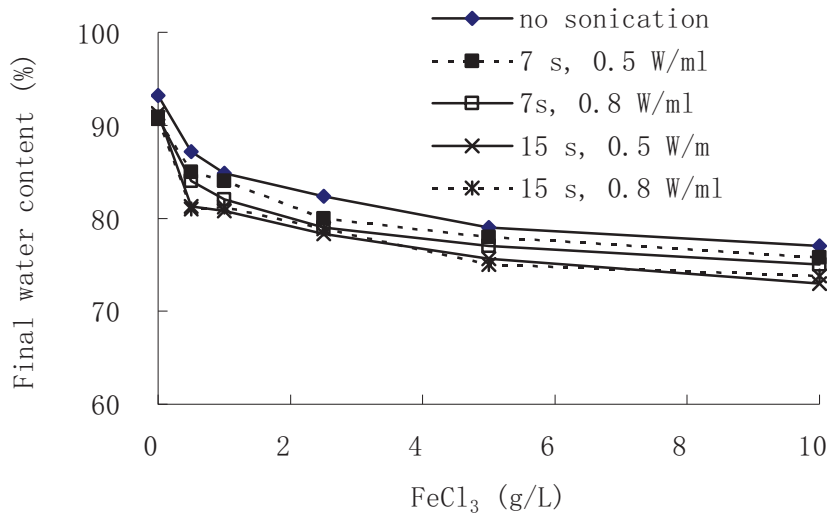
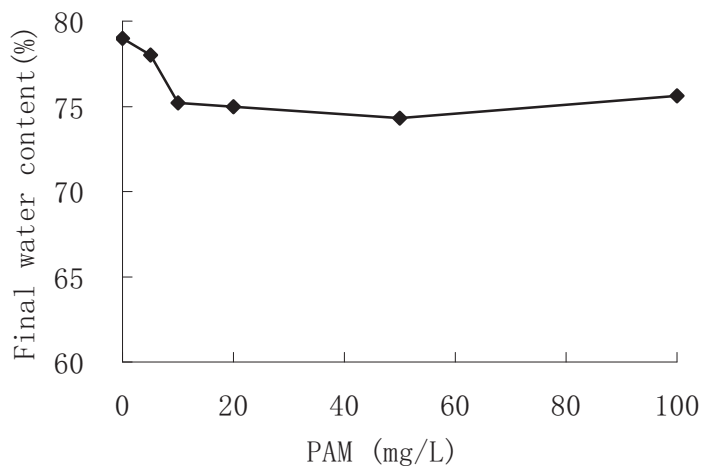
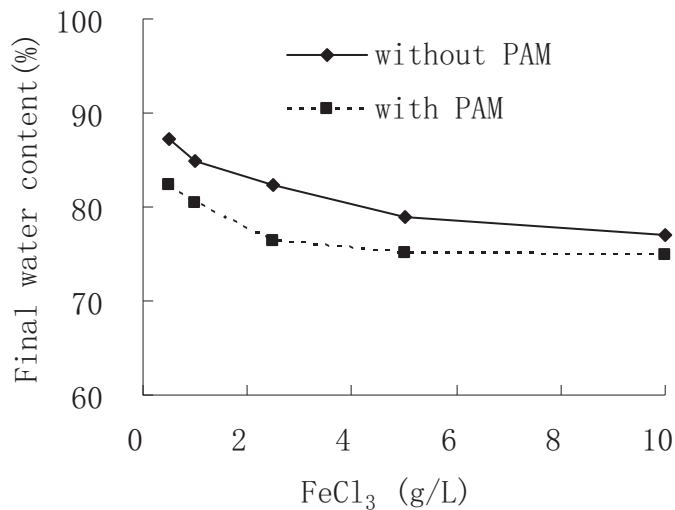


Fig. 4 Co-conditioning of sonication and FeCl₃

3.3 Co-conditioning of sonication, FeCl₃, and PAM

In order to further reduce the chemical dose and improve sludge dewatering, we studied sludge chemical conditioning by adding some PAM together with FeCl₃, which is a common practice in wastewater treatment plants. Fig. 5 shows the results of PAM+ FeCl₃ conditioning. Clearly, small amount of PAM effectively enhanced the sludge dewatering and PAM/FeCl₃ ratio of 0.01 was sufficient (Fig. 5a). With addition of PAM, final water content of dry sludge reached 72% (Fig. 5b) and the total chemical dose was much lower. 25 mg/L PAM + 2.5 g/L FeCl₃ achieved a final water content of 75.9%, equal to the potency of 10.0 g/L FeCl₃.



a. Impact of PAM/FeCl₃ ratio, FeCl₃=5 g/Lb. Impact of FeCl₃ dose, PAM/FeCl₃=0.01Fig. 5 Sludge conditioning using FeCl₃ and PAM

Finally, we combined all three treatments together, and Fig. 6 reports the results of hybrid conditioning of sonication-PAM/ FeCl₃. Four different sonication conditions and three levels of chemical doses were tested. The optimal sonication, again, was found to be 7 s and 0.8 W/ml. Therefore, the best sonication for sludge conditioning, alone or together with chemicals, was 7 s and 0.8 W/ml. With the aid of sonication, 1.5 g/L FeCl₃ + 15 mg/L PAM reduced the final water content to below 75%, equal to the potency of 2.5 g/L FeCl₃ + 25 mg/L PAM. Therefore, sonication at 0.8 W/ml for 7 s (960 kJ/kgDS) could save 40% chemicals.

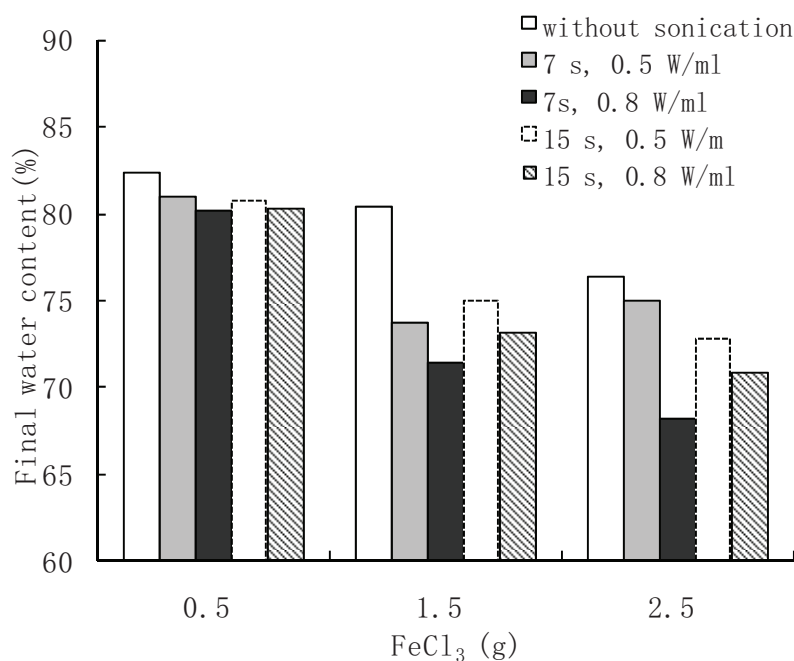


Fig. 6 Sludge co-conditioning by sonication, FeCl₃, and PAM, PAM/FeCl₃=0.01

3.4 Discussion on sonication energy, SRF, and final water content

We examined the relationship between the energy input of all four sonication conditions and the corresponding sludge SRF and final water content. Fig. 7 summarizes the findings. For sonication alone, sludge SRF dropped sharply with the ultrasonic energy; however, the SRF decrease had an upper limit of 40%, which was insufficient for good dewatering and the final water content was still higher than 90%.

Chemical conditioning, on the other hand, was much more effective for sludge SRF decrease and final water content reduction. Addition of FeCl₃ neutralized the negative charge of sludge and thus cut the sludge SRF by more than 50% and, hence, reduced the final water content to 80%. Another benefit of FeCl₃ was that Fe(III) effectively reduce the supernatant turbidity due to its flocculation capability (Fig. 3). Addition of PAM, a polyelectrolyte with a molecular weight of ~12 million Dalton, could greatly increase the size of the sludge flocs. Sludge particle size strongly affected its dewaterability and optimal value of particle size varied among different types of sludge from various sources. In general, bigger particles, with smaller surface areas, attract less water on the surface. As a result, the sludge SRF was further reduced to around 10% of the original value (Fig. 7) and the final water content was below 75%.

When both sonication and chemicals were used, sonication did not help much in sludge SRF reduction, which agreed with the finding of Yin [7] and Feng [2]. A potential explanation is that: sonication increases the supernatant organic contents (SCOD) (Fig. 1), which then act as flocculant to reduce the number of small particles presented in sludge. Such a flocculation effect contributes to the decrease of SRF. However, the flocculation effect is weak and might be 'shadowed' when strong flocculants such as FeCl₃ and PAM are used. With FeCl₃ and PAM, large flocs formed a permeable and rigid lattice structure and altered the sludge compressibility by remained porous during dewatering [19]. The real advantage of

sonication in sonication-chemical co-conditioning was to save chemicals. Under optimal conditions, the chemical dose (both FeCl_3 and PAM) could be reduced by 40-50%; Yin [7] also reported a 25-50% flocculant saving.

Fig. 7 also showed that SRF was not a direct index for water dewatering. For example, the sludge SRF with 1280 kJ/kgDS sonication was similar to that with 2.5 g/L FeCl_3 , but the final water content was very different (91.3% vs. 82%). For the case of 2.5 g/L FeCl_3 , the lowest SRF occurred when the sonication energy was 1960 kJ/kgDS while the lowest final water content occurred when the sonication energy was 960 kJ/kgDS. Since the purpose of sludge conditioning was to improve the sludge dewatering process to achieve drier sludge, final water content is a better index to describe sludge dewaterability than SRF.

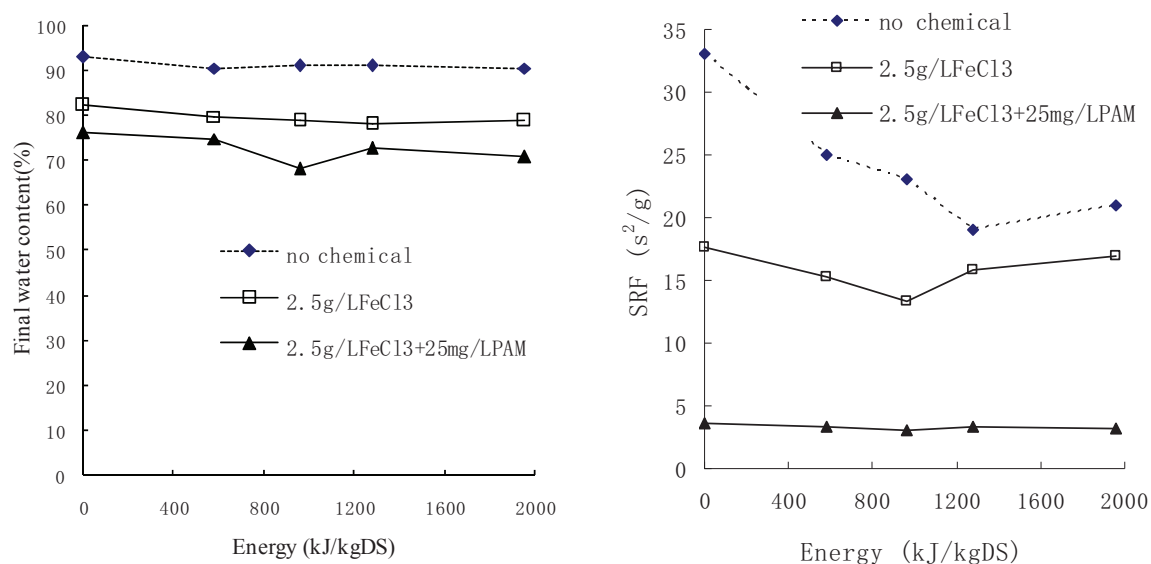


Fig. 7 Impact of sonication energy on sludge dewatering

4. Conclusions

This paper investigated the effects of sonication for sludge conditioning, alone or in together with chemicals. Final water content of dry sludge and sludge specific resistance to filtration (SRF) were monitored. Various sonication conditions and FeCl_3 and PAM doses were examined. Sonication was found to effectively change the dewaterability of sludge when applied alone. Proper sonication energy was below 1200 kJ/kgDS and the best value 960 kJ/kgDS (7 s and 0.8 W/ml); sludge SRF decreased by 40%. However, sonication alone was insufficient for sludge conditioning and combination of chemical conditioning was necessary. In the sonication-chemical co-conditioning, sonication save the chemical dose by 40-50% but did not impact the sludge SRF. The optimal conditioning was sonication for 7 s at 0.8 W/ml, 1.5 g/L FeCl_3 , and 15 mg/L PAM, which gave a final water content of 72.8%. Final water content was a better index than SRF for describing the sludge dewaterability.

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